International Journal of
Intelligent Engineering & Systems

http://www.inass.org/

Development of Low Profile M-Shaped Monopole Antenna for Sub 6 GHz Bluetooth, LTE, ISM, Wi-Fi and WLAN Applications

Madhavi Devi Lanka[1]* **Subbarao Chalasani[1]**

[1]*School of Engineering, Career Point University, Kota, India*
* Corresponding author's Email: lankamadhavidevi@gmail.com

Abstract: A low profile and highly efficient M-Shaped monopole antenna has been designed and its analysis is presented in this work. The designed model can work in the sub 6 GHz band with coverage in the communication applications like Bluetooth(2.4 GHz), Long Term Evolution LTE (2.45 GH), Industrial Scientific and Medical Band ISM(2.5 GHz), Wireless Fidelity Wi-Fi (3.1 GHz) and Wireless Local Area Network WLAN (5.5 GHz) respectively. It has been built on commercially available FR4 material with dimensions of 37X26X1.6 mm. Electromagnetic simulation-based modelling with optimization has been done and presented in this work. An average gain of 3.8 dB, average directivity of 3.2 dB and attained average efficiency reading of 82% from the current design. The results obtained in real time measurement with respect to reflection coefficient, gain, radiation characteristics and Voltage Standing Wave Ratio VSWR are matching with the results obtained in the simulation.

Keywords: Compact antenna, M-Shaped monopole, Sub 6 GHz, WLAN.

1. Introduction

The fast-growing technology demanding several advanced antenna modules for reception and transmission of signals for faithful communication. The modern antennas need several additional features to fit them as suitable devices in these communication systems. Compactness, conformability, adoptability, high performance with suitable bandwidth and radiation characteristics makes the difference in any antenna design. The design aspects should focus on various parameters and need to satisfy the real time conditions as per the application orientation.

Design of antenna model for modern communication applications, which fall under sub 6 GHz application is the most demandable job for research community. Abhijuru [1] designed a coplanar wave guide fed tapered slot antenna for wireless communication applications with beam switching capability. Abouelnaga [2] produced a Multi Input Multi Output MIMO antenna with 10X10 elements for 5G communication applications which fall under sub 6 GHz range. Alieldin [3] designed dual polarized triple band antenna for various communication applications of 2G, 3G, 4G and 5G with sub 6 GHz band coverage. Asif [4] designed a quad band antenna with controllable tuning capability to serve the 5G new radio communication applications. Bayarmaa [5] proposed a compact planar inverted folded antenna for mobile applications which is covering Personal Communication Systems PCS, Bluetooth, and Wi-Fi communication. Hyuang [6] designed a hybrid mode antenna for communication applications under Sub 6 GHz band. Kolusu [7] produced triple band antenna with concentric ring structure for wireless communication applications.

The designed model is covering three bands with bandwidth of 13%, 25% and 32% respectively with moderate gain. Pokkunuri [8] designed a metamaterial based multiband monopole antenna of fractal structure. The modelled structure is capable of reconfigurability in the design to switch between various communication bands with PIN diode biasing. Jin [9] analyzed a differentially fed monopole antenna with frequency reconfigurability to switch between Sub 6 GHz bands and produced average gain of 3.2 dB with average efficiency of 72%. Khujhali [10] proposed a wide bandwidth microstrip antenna model for quadband mobile and commercial communication applications. This model is having compact dimension with average gain of 2.9 dB and radiation in boresight direction of propagation.

Kulkarni designed triple folded monopole antenna for laptop devices and ultrathin antenna model for communication applications [11, 12]. Kurvinen and Li H proposed antenna models for mm-wave communication and Sub 6 GHz communication applications [13, 14]. Ren [15] designed dual band multiple input multiple output self-decoupled antenna for 5G communication applications which fall under Sub 6 GHz bands. Trang [16] and Rekha [17] designed compact monopole antenna of notch characteristics useful to wireless communication applications. Wang [18] and Medhal [19] designed wideband monopole antenna models for lower band communication systems. Different monopole antennas with defected ground structures, reconfigurability and metamaterial concepts are designed by the researchers in the literature. Flared shaped monopole is designed by Ajay with metamaterial loading for lower band communication applications [20]. Mohan produced asymmetric ground-based monopole antenna for addressing various wideband communication applications [21]. Venkat [22] designed circular monopole notch antenna with split ring resonators for blocking certain unwanted bands and to improve the gain. Rajiya designed a frequency tunable monopole antenna to swift the operating bands to cater the needs of modern communication applications [23].

Notch band monopole antenna with filtering characteristics is proposed by Vijaya Lakshmi [24] to block Wi-Fi and WLAN. Sanjay analyzed a circular monopole suitable for vehicular bands to receive signals in intra vehicular communication [25]. Lakshmi designed a parasitic monopole notch band antenna to hold triple band characteristics with defected ground structure [26]. Tilak analyzed heart shaped monopole antenna backed by artificial-magnetic-conductor to improve the efficiency [27]. Orthogonal MIMO antenna with combination of monopole structures designed by Rekha [28] for the improvement of isolation between the elements to reduce mutual coupling. Slimani [29] produced ultrawide band coupler suitable for 5G communication applications. Pronami [30] analyzed a monopole antenna with electromagnetic band gap structure for Wi-Fi, LTE and WLAN applications.

Vineetha [31] designed conformal and flexible microwave absorbers for ISM, Wi-MAX and WLAN applications. Ram prasad [32] designed a Microelectronic Mechanical Systems MEMS based reconfigurable antenna for wireless communication applications. Srilatha [33] analyzed a wearable monopole antenna on jeans substrate for off body communication applications at ISM band. Jayanth [34] designed a concentric ring structured monopole antenna for wearable communication applications with AMC backing. Jute substrate-based monopole antenna is designed by Sandeep [35] for ISM, Wi-MAX and WLAN applications in wearable communication.

Researchers proposed several antenna models with various techniques like defected ground, metamaterial structure and reconfigurable analysis to alter the resonant frequencies and radiation pattern. The individual advantages in each model are grouped and with the combination of slotting and DGS, the proposed model is designed to cover desired operating bands with reasonable gain.

2. Novelty and methodology

The current design is a compact monopole M-shaped microstrip patch antenna with defected ground for Sub 6 GHz communication applications. In the literature several antenna models are designed and analyzed for various wireless mobile communication applications. The disadvantages observed in the literature are mainly moving around the larger dimension, lower bandwidth, low efficiency and low gain. The gain and the bandwidth as well as size of the antenna and wavelength are inversely proportional to each other. To balance and optimize all the antenna output parameters, a novel design with defected ground has been proposed in this work. The size is compact and obtained gain and efficiency is better in the proposed model in comparison with existing designs.

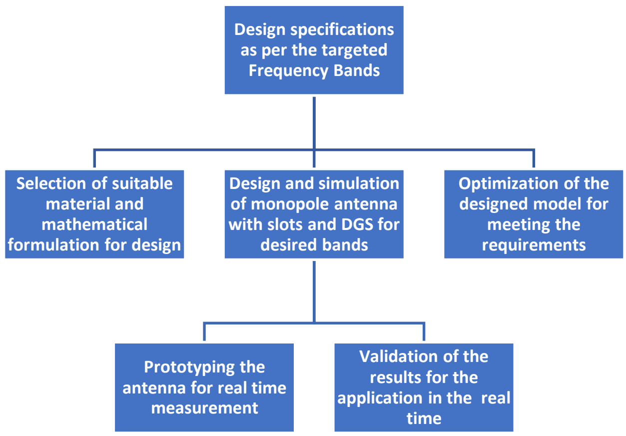


Figure. 1 Designed methodology

The design methodology has been given in Fig. 1. The complete organization of the process from specification to measurement on the fabricated model is showcased here for the clear explanation. The material characteristics are analyzed prior to the usage of the material in the design analysis and using electromagnetic simulation tool the complete modelling and optimization has been done. Prototype measurement has been done with vector network analyzer in closed chamber and presented.
The designed model dimensional characteristics and design parameters are discussed in antenna geometry section and the analysis with output parameters are discussed in results and discussion sections.

3. Antenna geometry

The antenna model with design parameters are presented in Fig. 2(a). The final dimension value of the antenna is around 37X26x1.6 mm on FR4 dielectric substrate material of relative permittivity 4.4 and loss tangent of 0.25. M-shaped radiating monopole structure with microstrip line feeding has been used in the design of the antenna. The ground structure is of partial ground orientation with two strips on either side of the feedline with slot gap in between them as presented in Fig. 2(b). The resonant frequency at lower band can be determined using the Eq. (1).

$$F_L = \frac{C}{\lambda} \tag{1}$$

where ‘ C ’ is velocity of light and ‘ λ ’ is the wavelength

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1+\frac{10h}{w}}} \tag{2}$$

where ‘ε_r’ is permittivity, ‘h’ is the height of the substrate and ‘w’ is the width of the patch.
The effective length of the patch can be calculated using the Eq. (3).

$$L_e = \frac{c}{2f_0\sqrt{\varepsilon_{eff}}} \tag{3}$$

The prototyped antenna parameters are measured with vector network analyzer in Anechoic chamber. To get good impedance matching between the prototyped antenna and the measuring instrument, 50 ohm SMA connector has been soldered to antenna feedline. The antenna parameters of gain and radiation pattern are measured with antenna radiation measurement setup at ALRC-R&D. Antenna

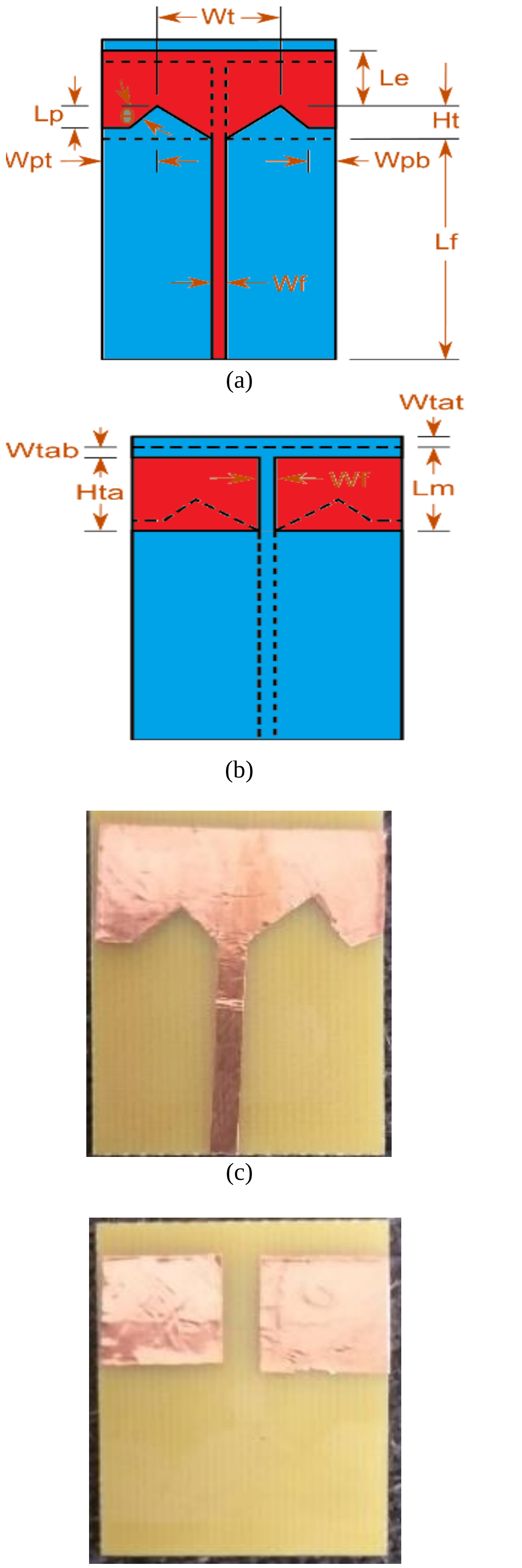


Figure. 2 Antenna geometry: (a) Top View, (b) Bottom View, (c) Prototype Top View, and (d) Prototype Bottom View

Received: June 14, 2021. Revised: August 12, 2021.

Table 1. Antenna dimensional characteristics

S. No	Description	Parameter	Dimension in mm
1	Length of the feed line	Lf	24.7
2	Width of the feed line	Wf	3.1
3	Top arm width	Wtat	8.3
4	Bottom arm width	Wtab	8.3
5	Triangular element width	Wt	13.3
6	Triangular element height	Ht	3.3
7	Trapezoidal element length	Lp	2.5
8	Trapezoidal top arm width	Wpt	3.7
9	Rectangular element length	Le	8.2
10	Trapezoidal angle	ϴ	56.3^0
11	M-Element length	Lm	11.5
12	T arm height	Hta	10.7
13	Trapezoidal base width	Wpb	2
14	Total length of the antenna	Ytot	37
15	Substrate Material	FR4	Ɛr=4.4

measurement setup has been shown in Fig. 8.Stable gain horn antenna has been placed on transmission side and the designed monopole antenna has been placed in reception side. Turn table mechanism with measurement software analysis is done for capturing radiation patterns and gain.

4. Results and discussion

CST microwave studio has been used to design the antenna model and the simulation analysis with optimization of output parameters are carried out in frequency domain. Fig. 3 shows the analysis of $S_{11}$and the VSWR with respect to frequency of operation. Antenna working in the range of 2.4 GHz to 5.6 GHz with bandwidth of 3.2 GHz and impedance bandwidth of 80%. The commercial communication applications like ISM, Bluetooth, LTE-4G, Wi-Fi, 5G and WLAN are covering under Sub 6 GHz bands through the proposed antenna model. The VSWR in 2:1 ratio at desired band supporting the bandwidth for earmarked applications.

The impedance matching of 50 ohms is maintained while designing the antenna model and it has been achieved through the selection of propoer dimensions in feed line length and width as per the radiating structure dimension. Fig. 4 shows the impednce characteristics of the antenna with respect to frequency of operation. The average impedance

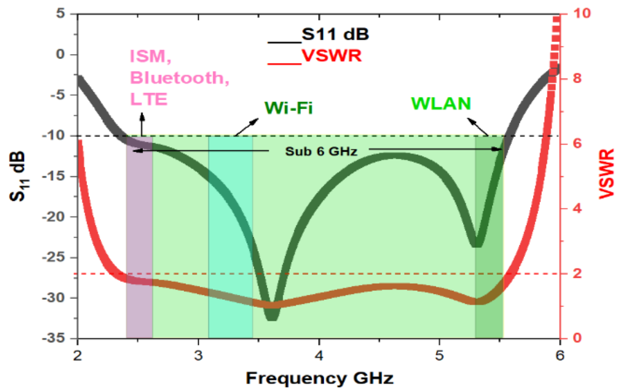


Figure. 3 S_{11} and VSWR vs frequency

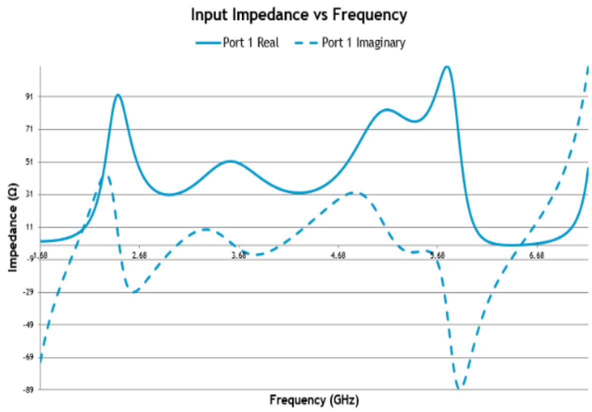


Figure. 4 Impedance vs frequency

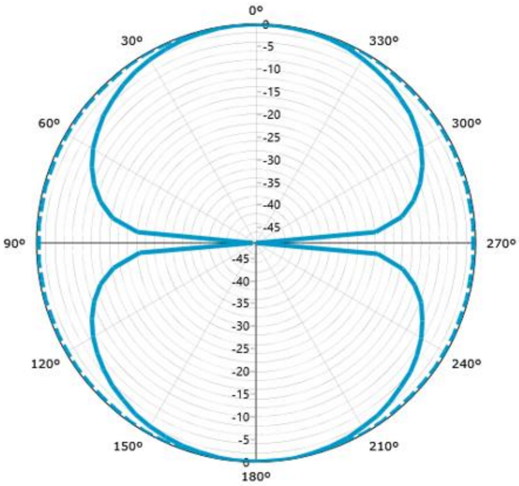
obtained in the band is around 46 ohms and which is the good sign for the fabrication of the antenna model.

The radiation characteristics of the antenna at three differnet operating bands in Sub 6 GHz are presented in Fig. 5 and 6. Fig. 5 shows the raiation pattern in polar coordinates for the antenna at 2.4 GHz, 3.1 GHz and 5.5 GHz respectively. At 2.4 GHz, antenna showing dipole like radiation and at 3.1 GHz, antenna showing directive pattern. Antenna providing quasi omnidirectional pattern at 5.5 GHz. The two dimensional radiation characteristics with respect to angle theta has been presented in Fig. 5 (d), 5 (e) and 5 (f) respectively.

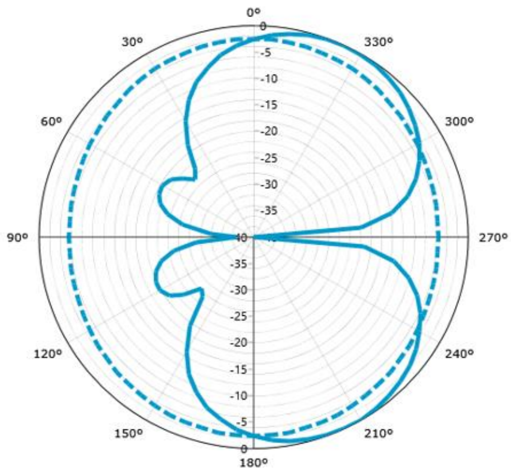
The three dimensional radiation analysis and the 2D-cartesian analysis has been presented for gain and directivity in Fig. 6. Gain of 2.4 dB from 3D radiation curve of Fig. 6(a) and directivity of 2.17 dB from cartesian plot of Fig. 6(b) can be observed from the simulation characteristics.

Fig. 6. Gain of 3.03 dB from 3D radiation curve of Fig. 6(c) and directivity of 3.07 dB from cartesian plot of Fig. 6(d) can be observed from the simulation characteristics. Fig. 6. Gain of 4.63 dB from 3D radiation curve of Fig. 6 (e) and directivity of 4.75 dB from cartesian plot of Fig. 6 (f) can be observed from the simulation characteristics.

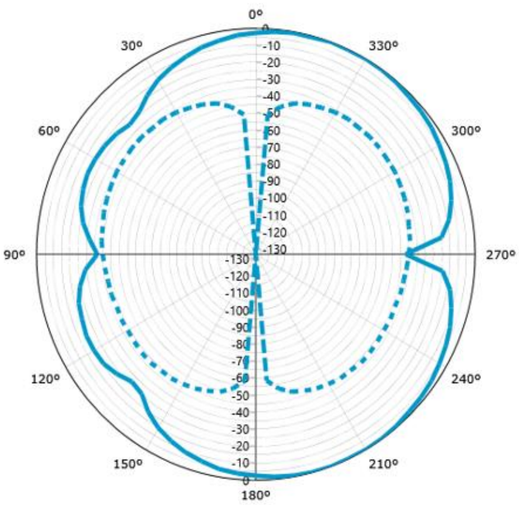
Received: June 14, 2021. Revised: August 12, 2021.



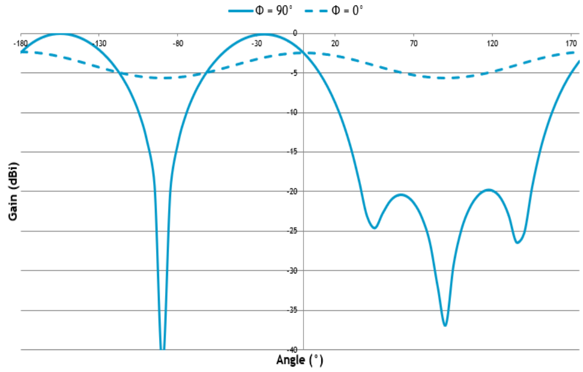
(a)



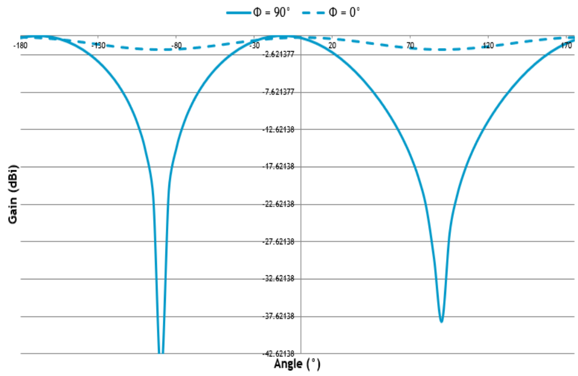
(b)



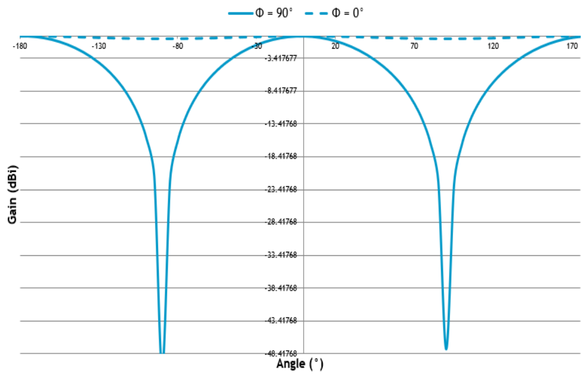
(c)



(d)



(e)



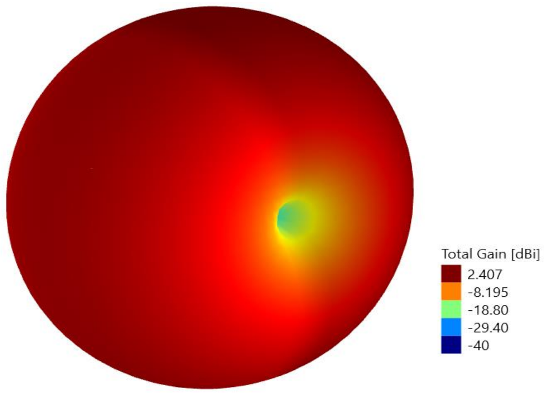
(f)

Fig 5. Radiation pattern in polar and in 2D: (a) Polar at 2.4 GHz, (b) Polar at 3.1 GHz, (c) Polar at 5.5 GHz, (d) 2D at 2.4 GHz, (e) 2D at 3.1 GHz, and (f) 2D at 5.5 GHz

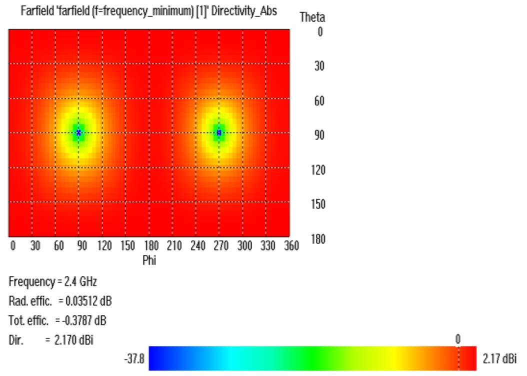
The time domain response of the designed antenna is analyzed and presented in Fig. 7. The input pulse and the impulse response is with respect to time in nano seconds is presented here. The corresponding response to the input pulse in time domain mode is analyzed and attained quick response in 0.2 n/s.

A comparative analysis with the antenna models presents in the Table 2 giving strong evidence regarding the novelty of the current model. The size, operating bands, efficiency and gain are superior when compared with current literature and the applicability in the desired field is most suitable as per the obtained results.

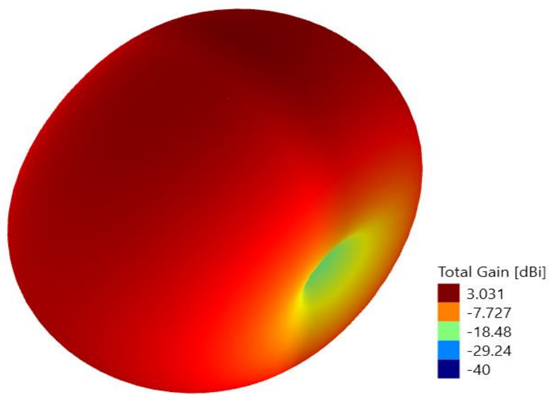
Received: June 14, 2021. Revised: August 12, 2021.



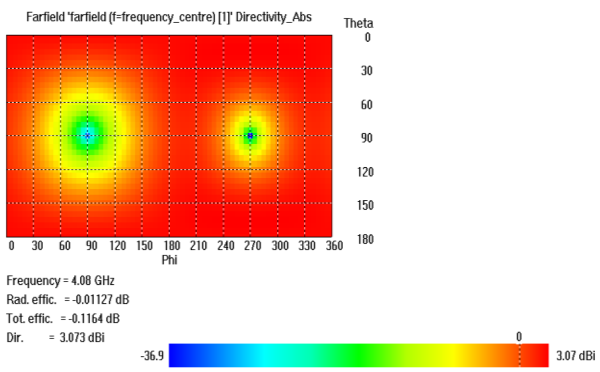
(a)



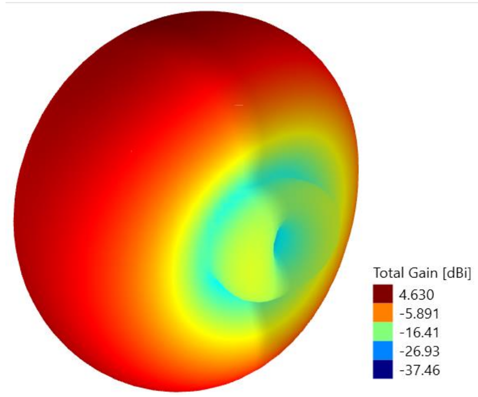
(b)



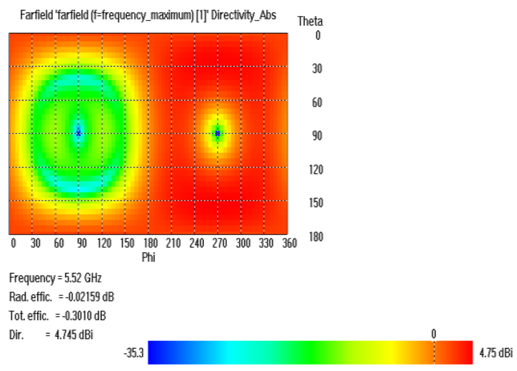
(c)



(d)



(e)



(f)

Figure. 6 3D radiation and 2D-cartesian plots: (a) and (b) 2.4GHz, (c) and (d) 3.1GHz, (e) 5.5GHz, and (f) 5.5GHz

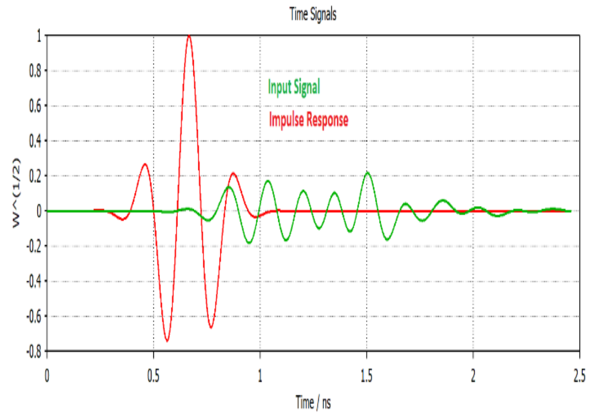


Figure. 7 Time domain response

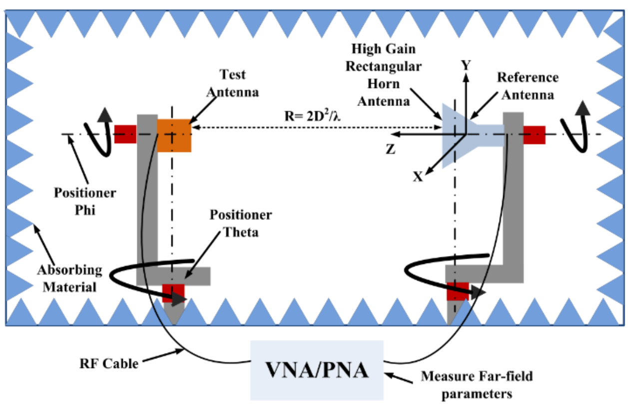


Figure. 8 Antenna measurement setup

Table 3. Comparative analysis

Ref . No	Size (mm)	Operating Bands GHz	Avg Gain in dB	Avg Efficiency %
[3]	38x34	0.9, 2.4	2.8	76
[4]	40x36	2.4, 3.6	3.2	80
[6]	42x38	2.45, 3.2	2.9	74
[7]	48x44	2.4, 3.1	2.8	72
[11]	38x32	2.4	2.6	77
[14]	37x35	2.4, 3.1	2.5	75
[17]	40x38	3.1,4.6,5.8	3.1	73
[22]	42x38	3.1,4.6, 5.8	2.9	76
[24]	44x42	2.8,3.4, 5.8	3	72
[26]	42x40	3.6, 5.8	3.2	74
[33]	45x43	2.8,4.6, 6.2	3.2	72
[35]	40x38	2.4,3.1, 5.8	2.9	76
This work	37x26	2.4, 2.5, 3.1, 5.5	3.8	82

5. Conclusion

M-Shaped monopole antenna designed and analyzed for sub 6 GHz band applications with coverage in ISM(2.5 GHz), Bluetooth(2.4 GHz), LTE (2.45 GH), Wi-Fi (3.1 GHz) and WLAN (5.5 GHz) communication applications.

Antenna occupied the compact dimension of 37x26x1.6 mm on commercial dielectric material of FR4 and the measured results in the anechoic chamber perfectly correlating with the EM-simulation results attained from electromagnetic tool.

An average gain of 3.8 dB, average directivity of 3.2 dB and average efficiency of 82% is obtained from the proposed model and providing suitability for the commercial communication applications.

The presented antenna model is a potential candidate for lower band commercial wireless communication applications with good impedance matching and radiation characteristics.

Conflicts of Interest

The authors declare no conflict of interest

Author Contributions

Conceptualization, Simulation and Original draft preparation was done by Madhavi Devi Lanka. Formal analysis, supervision and validation was done by Subbarao Chalasani.

References

[1] D. Abijuru, M. R. Hamid, N. Seman, and M. Himdi, "A coplanar waveguide tapered slot antenna with beam switching capabilities", *Indonesian Journal of Electrical Engineering and Computer Science*, Vol. 20, No. 1, pp. 275-280, 2020.

[2] T. G. Abouelnaga, I. Zewail, and M. Shokair, "Design of 10 ×10 Massive MIMO Array in Sub-6GHz Smart Phone for 5G Applications", *Progress in Electromagnetics Research B*, Vol. 91, pp. 97-114, 2021.

[3] A. Alieldin, Y. Huang, and S. J. Boyes, "A Triple-Band Dual-Polarized Indoor Base Station Antenna for 2G, 3G, 4G and Sub-6 GHz 5G Applications", *IEEE Access*, Vol. 6, pp. 49209-49216, 2018.

[4] S. M. Asif, M. R. Anbiyaei, and K. L. Ford, "Low-Profile Independently-and Concurrently-Tunable Quad-Band Antenna for Single Chain Sub-6GHz 5G New Radio Applications", *IEEE Access*, Vol. 7, pp. 183770-183782, 2019.

[5] O. Bayarmaa, K. Kim, and Y. Lee, "Design of triple–band planar inverted-F antenna for 0.9/2.4/3.6 GHz wireless applications", *International Journal of Multimedia and Ubiquitous Engineering*, Vol. 9, No. 10, pp. 129-136, 2014.

[6] B. Huang, W. Lin, J. Huang, J. Zhang, G. Zhang, and F. Wu, "A patch/dipole hybrid-mode antenna for Sub-6GHz communication", *Sensors*, Vol. 19, No. 6, 2019.

[7] S. S. R. Kolusu, A. B. Modala, B. T. P. Madhav, and B. P. Nadh, "Concentric circular ring loaded triple band antenna for wireless applications", *International Journal of Intelligent Engineering and Systems*, Vol. 12, No. 5, pp. 241-248, 2019.

[8] P. Pokkunuri, B. T. P. Madhav, G. K. Sai, and M. Venkateswararao, "Metamaterial inspired reconfigurable fractal monopole antenna for multiband applications", *International Journal of Intelligent Engineering and Systems*, Vol. 12, No. 2, pp. 53-61, 2019.

[9] G. Jin, C. Deng, and J. Yang, "A new differentially-fed frequency reconfigurable antenna for WLAN and sub-6GHz 5G applications", *IEEE Access*, Vol. 7, pp. 56539-56546, 2019.

[10] S. Khuzhali, "Wide Branch MSA for quadra band wireless applications", *Middle - East Journal of Scientific Research*, Vol. 20, No. 3, pp. 364-368, 2014.

[11] J. Kulkarni, "Multiband triple folding monopole antenna for wireless applications in the laptop computers", *International Journal of Communication Systems*, Vol. 34, No. 8, 2021.

[12] J. S. Kulkarni, "An ultra-thin, dual band, Sub 6 GHz, 5G and WLAN antenna for next generation laptop computers", *Circuit World*, Vol. 46, No. 4, pp. 363-370, 2020.

[13] J. Kurvinen, R. M. Moreno, and A. Lehtovuori, “Capacitively-Loaded Feed Line to Improve mm-Wave and Sub-6 GHz Antenna Co-Existence”, *IEEE Access*, Vol. 8, pp. 139680-139690, 2020.

[14] Y. Cheng, L. Mei, and L. Guo, “Frame Integrated Wideband Dual-Polarized Arrays for Mm-Wave/Sub 6-GHz Mobile Handsets and Its User Effects”, *IEEE Transactions on Vehicular Technology*, Vol. 69, No. 12, pp. 14330-14340, 2020.

[15] Z. Ren and A. Zhao, “Dual-Band MIMO Antenna with Compact Self-Decoupled Antenna Pairs for 5G Mobile Applications”, *IEEE Access*, Vol. 7, pp. 82288-82296, 2019.

[16] N. D. Trang, D. H. Lee, and H. C. Park, “Compact printed CPW-fed monopole ultra-wideband antenna with triple sub-band notched characteristics”, *Electronics Letters*, Vol. 46, No. 17, pp. 1177-1179, 2010.

[17] V. S. D. Rekha, P. Pardhasaradhi, B. T. P. Madhav, and Y. U. Devi, “Dual band notched CPW fed printed monopole antenna for UWB applications”, *International Journal of Intelligent Engineering and Systems*, Vol. 13, No. 3, pp. 26-32, 2020.

[18] Y. Wang, L. Zhu, and H. Wang, “Design of compact wideband meandering loop antenna with a monopole feed for wireless applications”, *Progress in Electromagnetics Research Letters*, Vol. 73, pp. 1-8, 2018.

[19] B. K. Medhal, P. Jayappa, and J. Shivamurthy, “Design of minkowski fractal iteration in monopole patch antenna”, *International Journal of Intelligent Engineering and Systems*, Vol. 13, No. 5, pp. 549-559, 2020.

[20] M. A. babu, D. N. Vaishnavi, P. Radhakrishna, N. Bharath, K. Madhuri, K. B. Prasad, and K. Harish, “Flared V-Shape Slotted Monopole Multiband Antenna with Metamaterial Loading”, *International Journal of Communications Antenna Propagation*, Vol. 5, No. 2, pp. 93-97, 2015.

[21] S. S. M. Reddy and P. M. Rao, “Asymmetric Defected Ground Structured Monopole Antenna for Wideband Communication Systems”, *International Journal of Communications Antenna and Propagation*, Vol 5, Issue 5, Dec-15, pp. 256-262.

[22] M. V. Rao and T. Anilkumar, “Conformal Band Notched Circular Monopole Antenna Loaded with Split Ring Resonator”, *Wireless Personal Communications*, pp. 1-12, 2018.

[23] S. Rajiya, B. P. Nadh, M. S. Kumar, “Frequency reconfigurable monopole antenna with DGS for ISM band applications”, *Journal of Electrical Engineering*, Vol. 69, No. 4, pp. 293-299, 2018.

[24] M. V. Lakshmi and P. Pardhasaradhi, “Circular Monopole Reconfigurable Antenna with Notch Band Filter Characteristics”, *Journal of Engineering Science and Technology Review*, Vol. 11, Issue 5, pp 139-143 2018.

[25] S. Bandi, D. K. Nayak, and A. Tirunagari, “Transparent Circular Monopole Antenna for Automotive Communication”, *ACES Journal*, Vol. 34, No. 5, pp. 704-708 2019.

[26] M. L. S. N. S. Lakshmil, H. Khan, M. V. Rao, and G. L. Madhumati, “Triple Notch Reconfigurable Parasitic Monopole Patch Antenna with Defected Ground Structures”, *International Journal of Microwave and Optical Technology*, Vol. 15, No. 4, pp. 318-324 2020.

[27] G. B. G. Tilak, S. K. Kotamraju, K. C. S. Kavya, and M. V. Rao, “Dual Sensed High Gain Heart Shaped Monopole Antenna with Planar Artificial Magnetic Conductor”, *Journal of Engineering Science and Technology*, Vol. 15, No. 3, pp. 1952-1971, 2020.

[28] V. S. D. Rekha, P. Pardhasaradhi, and Y. U. Devi, “Dual Band Notched Orthogonal 4-Element MIMO Antenna with Isolation for UWB Applications”, *IEEE Access*, Vol. 8, 2020.

[29] A. Slimani, S. Das, A. E. Alami, S. D. Bennani, and M. Jorio, “Phase shift switching of a miniaturized ultra-wideband hybrid coupler for 5G technology”, *Microwave and Optical Technology Letters*, pp. 1-6, 2020.

[30] P. Bora and P. Pardhasaradhi, “Design and Analysis of EBG Antenna for Wi-Fi, LTE, and WLAN Applications”, *ACES Journal*, Vol. 35, No. 9, pp. 1030-1036, 2020.

[31] K. V. Vineetha, M. S. Kumar, Y. U. Devi, and S. Das, “Flexible and conformal metamaterial-based microwave absorber for WLAN, Wi-MAX and ISM band applications”, *Materials Technology*, pp. 1-17, 2021.

[32] G. R. Prasad and P. Pardhasaradhi, “Concentric Ring Structured Reconfgurable Antenna using MEMS Switches for Wireless Communication Applications”, *Wireless Personal Communications*, 2021.

[33] K. Srilatha, B. A. Babu, M. R. Raj, T. Somala, V. Nimmaraju, and M. C. Rao, “Design and analysis of Jeans based Wearable monopole antenna with enhanced gain using AMC backing”, *Journal of Physics: Conference Series*, 2021.

[34] J. Reddy K, J. Vani, R. R. Priyanka, B. P. Nadh, M. C. Rao, “Concentric Ring Loaded Monopole Antenna with AMC Backed for Wearable

Received: June 14, 2021. Revised: August 12, 2021.

Applications”, *Journal of Physics: Conference Series*, 2021.

[35] D. R. Sandeep, N. Prabakaran, and K. L. Narayana, “Circularly Polarized Jute Textile Antenna for Wi-MAX, WLAN and ISM Band Sensing Applications”, *ACES Journal*, Vol. 35, No. 12, pp. 1493-1499, 2020.